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A Project Report

On

NON-INVASIVE BLOOD GLUCOMETER

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In

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(VISVESVARAYA TECHNOLOGICAL UNIVERSITY, BELAGAVI)

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ABSTRACT

Diabetes, a chronic condition characterized by elevated blood sugar levels, particularly type 2 diabetes, has seen a significant rise globally over recent decades, impacting individuals across various populations. Diabetes is associated with various health complications, including cardiovascular diseases, kidney failure, and neuropathy. Lifestyle factors such as diet, exercise, and weight management play a significant role in managing diabetes and preventing complications.

Access to affordable treatment, notably insulin, is crucial in managing diabetes and reducing associated risks. Monitoring blood sugar levels is crucial, and while both invasive and non-invasive methods exist, the techniques, like near-infrared (NIR) spectroscopy, offers a more comfortable option.

This study investigates the feasibility of NIR spectroscopy for non-invasive glucose measurement using the MAX30102 sensor. The sensor provides real-time glucose readings without invasive procedures by analyzing NIR light absorption by glucose particles in the blood. While promising, challenges such as noise interference and skin conditions require attention to optimize non-invasive glucometer performance. The development of such devices signifies a significant advancement in diabetes care, promoting convenience and adherence globally, with ongoing research poised to enhance patient outcomes further.

However, ongoing research and innovation could potentially transform diabetes care through non-invasive glucometers, leading to enhanced patient adherence and overall health improvements.

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LIST OF ABBREVIATIONS

NIR	Near Infra-Red
EMR	Electromagnetic Radiation
BGM	Blood Glucose Monitoring
DM	Diabetes Mellitus

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CHAPTER - 1

INTRODUCTION

Global advancements in patient monitoring systems, particularly multi-parameter devices, are being made with blood glucose (diabetics) as a primary focus to improve health maintenance. When combined with strong communication abilities, these technologies can promote healthier lifestyles in a manner like that of actual healthcare professionals. Diabetes, often known as diabetes mellitus, is a continual illness in which the insulin hormone controls blood sugar levels. Low insulin production results in raised blood sugar levels which is known as hyperglycemia, which can lead to problems with the kidneys, eyes, nerves, teeth, and heart. In addition, hypoglycemia is a problem that affects about 387 million people, according to a study. Given these challenges, timely treatment and glucose regulation are essential for assessing the quality of our blood glucose (diabetes) monitoring.

Diabetes is a chronic health condition characterized by elevated levels of sugar in the blood, which can lead to severe damage to the heart, blood vessels, eyes, kidneys, and nerves over time. The most common form is type 2 diabetes, often diagnosed in adults, where the body either resists the effects of insulin or does not produce enough of it. Over the past 30 years, the number of people with type 2 diabetes has significantly increased globally, affecting nations with various income levels. Another form is type 1 diabetes, formerly referred to as juvenile or insulin-dependent diabetes. In type 1 diabetes, the pancreas fails to generate enough insulin. Getting affordable treatment, especially insulin, is important for the well-being of people with diabetes. Globally, there is an objective to reduce the growth of diabetes and obesity by 2025. Currently, approximately 422 million people worldwide have diabetes, with a majority residing in nations with lower or middle incomes. Each year, 1.5 million deaths are directly attributed to diabetes. The prevalence and number of cases of diabetes have been steadily rising over the past few decades.

Blood sugar testing can be done at random or while fasting. When compared to random tests, the fasting state typically produces results that are easier to understand and more accurate. There are two methods for testing blood glucose (invasive and non-invasive). Common blood sugar diagnostic devices use invasive techniques that require drawing blood using a needle puncture wound on the skin and applying it to a chemically active test strip. As an alternative, non-invasive techniques including dielectric spectroscopy, ultrasound, and near-infrared (NIR) detection offer bloodless methods for performing and explicating blood glucose level test findings.

1.1 Motivation for the Work

Developing non-invasive glucometers is driven by the need to improve the experience of monitoring blood sugar levels for people with diabetes.

1. Comfortable Testing: They make checking blood sugar levels easier because they do not require pricking the skin like traditional methods do.
2. Different Technology: Instead of drawing blood, they use things like light or sound waves to measure glucose levels through the skin.
3. Easy to Use: You can use them by simply placing the device on your skin or wearing it like a watch.
4. Safer: Since they do not involve puncturing the skin, there is no risk of infections like there is with traditional methods.
5. Better Compliance: They are more comfortable, so people might be more likely to check their blood sugar levels regularly, which is important for managing diabetes well.

1.2 Objectives

The primary objectives of the capstone project are

- To develop a monitoring system that does not require invasive methods, ensuring a pain-free experience for the user.
- To provide a cost-effective and real-time blood glucose monitoring device.
- To design a portable device to monitor their blood glucose levels.

1.3 Organization of the Report

The report is organized into several chapters, each focusing on different aspects of the project. Chapter 1 introduces the topic, discussing global advancements in patient monitoring systems and the importance of monitoring blood glucose levels for individuals with diabetes. Chapter 2 presents a literature review, summarizing key research papers related to non-invasive glucose monitoring. In Chapter 3, the methodology section explains how glucose measurement is conducted using NIR spectroscopy, including data collection and analysis methods. Chapter 4 presents the results and discussions based on the analysis of the proposed project. Chapter 5 offers conclusions drawn from the study, and Chapter 6 discusses the future scope and implications of the project. The report also includes references, indicating the sources consulted, and an appendix listing the components used for the project.

CHAPTER - 2

LITERATURE REVIEW

Sl.No.	Paper Title	Author	Year	Key Points
1.	Optical-Based Non-Invasive Glucose Monitoring Sensor Prototype	Shyqyri Haxha, Jaspreet Jhoja	2016	• The sample is positioned between the NIR transmitter and receiver. • Sensor output is digitized using an ADC. • Calculation of adsorption and concentration is processed by Arduino LIFA module via LabVIEW.
2.	Non-invasive Blood Glucose Determination using Near Infrared LED in Diffused Reflectance Method	Mohammed Shahriar Arefin, Adnan Hossain Khan, Rabiul Islam	2018	• The proposed method uses a NIR LED (940nm) and a photo-detector to determine blood glucose concentration through the diffused reflectance method. • After implementing the device, data from the non-invasive method were compared with the proposed device output.
3.	Sensor system based Non-Invasive System to Measure Glucose Levels in Human Body	K T Sithara Surendran, T Sasikala	2019	• System uses a 940 nm LED and a photodiode in a finger clip for blood glucose measurement. • Arduino UNO processes photodiode output to calculate glucose levels. • Glucose level is displayed on a 16x2 LCD screen upon user finger insertion for real-time monitoring.

4.	A Study on Non-Invasive Blood Glucose Meter Providing Glucose Measurements Painlessly, Without A Blood Sample or Finger Pricks	Ujjas Saha	2020	• The MAX30100 sensor is employed for non-invasive measurement of blood glucose levels. • It utilizes two LED light sources to emit infrared and red light, respectively. • By analyzing the absorption levels of these light sources, the sensor determines the pulse rate and derives blood glucose content information.
5.	Design and Implementation of a Wearable System for Non-Invasive Glucose Level Monitoring	Md. Muntasir Islam, Md. Muntasir Islam	2019	• The proposed device uses Photoplethysmogram (PPG) and Galvanic Skin Response (GSR) sensors to measure blood glucose levels accurately. • By applying a deep learning algorithm to data from these sensors, the proposed system shows improved prediction error compared to conventional invasive methods.
6.	Portable Non-Invasive Glucometer using Near Infrared Sensor and Raspberry Pi	Isagani V. Villamor, Ruppert Ian R. Javier, Angelo O. Baloloy, N. Linsangan	2020	• NIR sensor calibrated and integrated with Raspberry Pi. • The algorithm on Raspberry Pi works with NIR LED and Photodiode. • User data stored in Raspberry Pi's memory with a microSD card, achieving 97.14% accuracy.

7.	An IoT-Based Non-Invasive Glucose Level Monitoring System Using Raspberry Pi	Antonio Alarcon-Paredes 1ORCID, Victor Francisco-Garcia, Jessica Cantillo	2019	• Utilizes an RPI Camera and a 650nm laser in the setup. • Blood glucose absorbs the light emitted by the laser. • RPI Camera captures this absorption, and glucose level is detected through image processing.
8.	Novel Approach to Non-Invasive Blood Glucose Monitoring Based on Transmittance and Refraction of Visible Laser Light.	Haider Ali, Fadi Jaber, Faycal Bensaali	2017	• The proposed system consists of a laser transmitter and a photo sensor. • The laser transmitter operates on +5V DC and emits continuous laser light. • A photo sensor, acting as a photo-transistor with sensitivity between 600 nm and 800 nm, detects laser light passing through a glucose sample, converting it to electrical energy.
9.	Fabrication and Validation of a Handheld Non-Invasive, Optical Biosensor for Self-Monitoring of Glucose Using Saliva	Amit Kumar Singh, Sandeep Kumar Jha	2019	• Saliva is collected on a biosensor strip containing multiple layers of enzymes and chemicals. • Sugar or glucose content in the saliva interacts with enzymes, inducing a change in pH activity. • This pH change causes a color alteration in the strip, indicating the presence and concentration of glucose.

10.	Non-Invasive Blood Glucose Detection along with an Assistive Diabetes Monitoring App	S A Aswathy, L Anusree	2018	• NIR spectroscopy measures blood glucose levels. • TCS32000 color sensor with four white LEDs serves as receiver. • Arduino UNO and driving circuit analyze and process signals. • Result sent via Bluetooth to the smartphone for storage.
11.	Detection of Blood Glucose Level in Humans Using Non-Invasive Method-RL BGM	M. Julie Therese, P. Dharanyadevi, A. Devi, C. Kalaiarasy	2020	• TGS822 tin oxide sensor used to measure acetone concentration in exhaled air. • Acetone concentration correlated with blood glucose level is measured. • Provides a non-invasive method for estimating blood glucose levels.
12.	Research on Non-invasive Glucose Concentration Measurement by NIR Transmission	Xiaoli Li, Chengwei Li	2015	• System uses laser transmitter, spectroscope, and thermal power meter heads. • S302C heads to ensure accurate low-power measurements. • PM100USB interface measures optical power and energy, aided by software. • In experiments, the laser beam split; one was measured directly, other through a glucose sample.

CHAPTER - 3

METHODOLOGY

In this method, the glucose measurement is done using NIR spectroscopy where the emitted light waves are in the spectrum of NIR. We predict the concentration of glucose present in the individual from the output obtained from the photodiode that is present in MAX30102 which is used to detect the light after absorption and transmission from glucose particles through the blood when the LED light is passed through the fingertip or ear lobule. The concept of near-infrared (NIR) spectroscopy is based on the absorption of electromagnetic radiation (EMR) at wavelengths ranging from 780nm to 2,500 nm. During light interaction with the sample, light waves of 940nm is sent from the MAX 30102 sensor and a detector measures its transmittance and absorbance. NIR spectroscopy is interested in both electronic and vibrational transitions. A NIR spectrophotometer measures light scattered off and through sample materials, enabling quick and accurate evaluation of their properties. The received light by the photodetector is inversely proportional to the amount of glucose present in the blood. The presence of glucose results in the absorption of the NIR light waves which results in lower current output at the photodetector of the MAX30102 sensor. The received light waves are measured in terms of current where the current is converted into voltage using a parallel resistance. The obtained voltage contains noise components and distortions due to skin roughness and water particles in the blood.

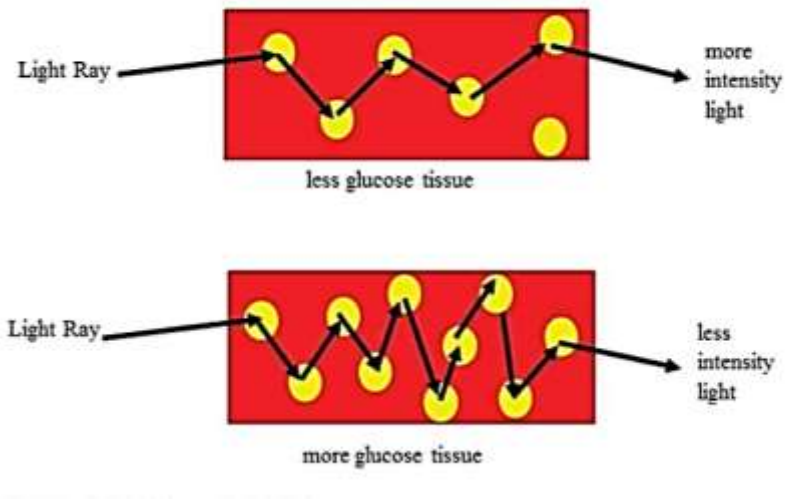

Figure 1: Effect of Glucose on Light Path

3.1 Research Design

The major purpose is to evaluate the output from the device and to compare the values with the database that is provided using invasive methods.
The research design could be classified as

- Experimental Groups: Divide the research area into two groups: one with the non-invasive method and one with the invasive method.
- Data Collection: It involves the collection of data from both invasive and non-invasive methods.
- Data Analysis: Use the measurements from the invasive method to compare and analyze it with the non-invasive data.
- Qualitative Feedback: Gather qualitative feedback from doctors, considering the experiences, challenges, and perceptions of the non-invasive techniques

3.2 Data collection and analysis

With the help of a designed system and commercially available invasive glucose measuring method (using glucose strips), glucose is measured for different people for different conditions like before and after meals, and corresponding voltage values at the amplifier output terminal and their respective glucose values are recorded. Based on the recorded voltage values and corresponding glucose concentration, a 1^{st} order polynomial regression equation is computed which is used to calculate glucose concentration. A regression equation can be defined as a statistical model, which is used to determine the specific relationship between the predictor variable and the outcome variable. A model regression equation allows for predicting outcomes with a very small error. Here, the predictor value is the analog output voltage received at the amplifier output and the outcome variable is the glucose value of the respective individual. The analog voltage measured at analog pin A0 of Arduino Uno / ESP8266 NodeMcu and the corresponding glucose concentration measured by the invasive method in the laboratory are plotted on a graph. The proposed regression equation processes as a Machine Learning Model which predicts the glucose level when the analog output voltage is fed into the model. The regression equation is calculated using MATLAB, based on the predictor and outcome variable graph plots are created and the regression equation is found out. The polynomial equation relating the analog voltage and the glucose level is computed by using a regression tool and shown below.

$y = 0.3027x – 2.0673$

where x and y are analog voltage (mV) and glucose level (mg/dl) respectively.

3.3 Block Diagram and Circuit Diagram

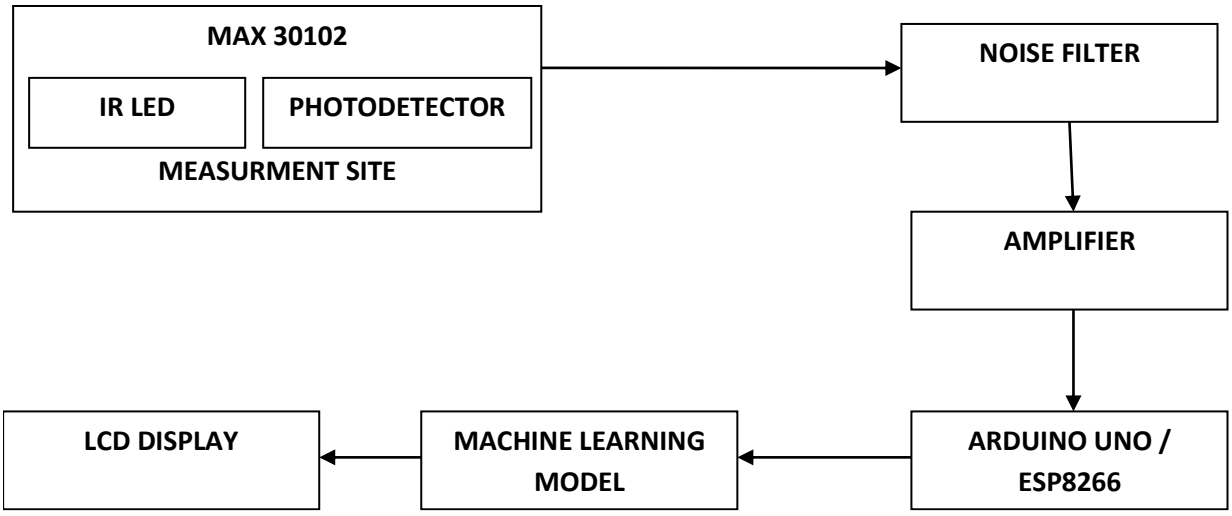

Figure 2 : Block Diagram

3.4 Ethical Considerations

In medical research, ethical considerations play a critical role, particularly in technologies that allow for non-invasive blood sugar monitoring. Crucial considerations and strategies for ensuring that the research is conducted correctly are as follows:

1. Obtaining Consent: The participants should be aware of the study's purpose, objectives, and potential issues before signing up.
2. How it will be done: For each participant demonstration will be provided at the beginning of the study attesting to their understanding of the procedures, potential risks, and the fact that they may withdraw from participation at any time.

3.5 Limitations

Non-invasive blood glucose monitoring may be less accurate than invasive methods, potentially leading to incorrect readings. Factors like skin conditions and moisture can affect the precision of non-invasive measures. Materials on the skin may interfere with the measurements, impacting accuracy. Additionally, non-invasive techniques might not offer real-time glucose readings promptly enough for situations requiring swift adjustments, such as insulin dosage.

CHAPTER - 4

RESULTS AND DISCUSSION

The circuit designed for noise cancellation and amplification of signal is simulated using Multisim for various values of photodiode. We obtained almost precise values of voltage.

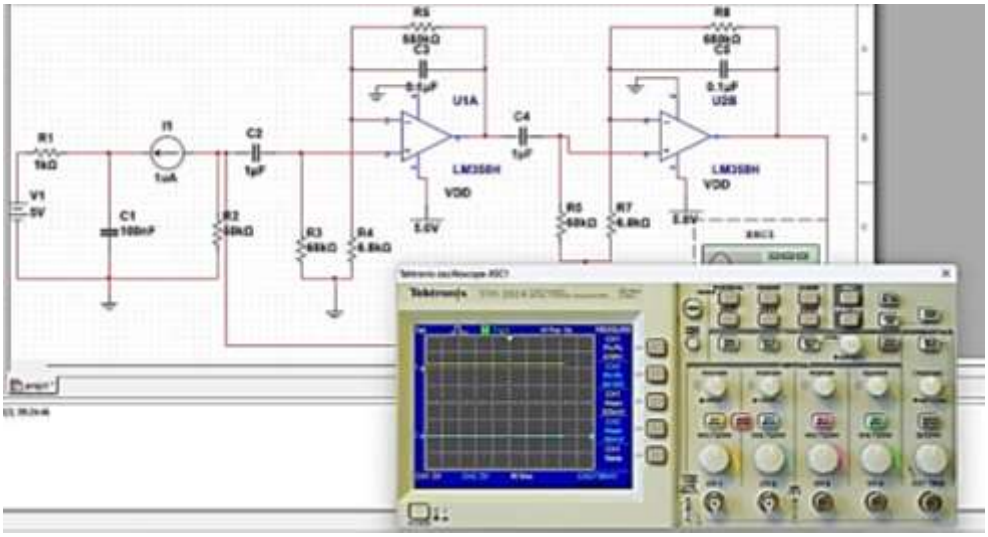

Figure 3: Output Waveform

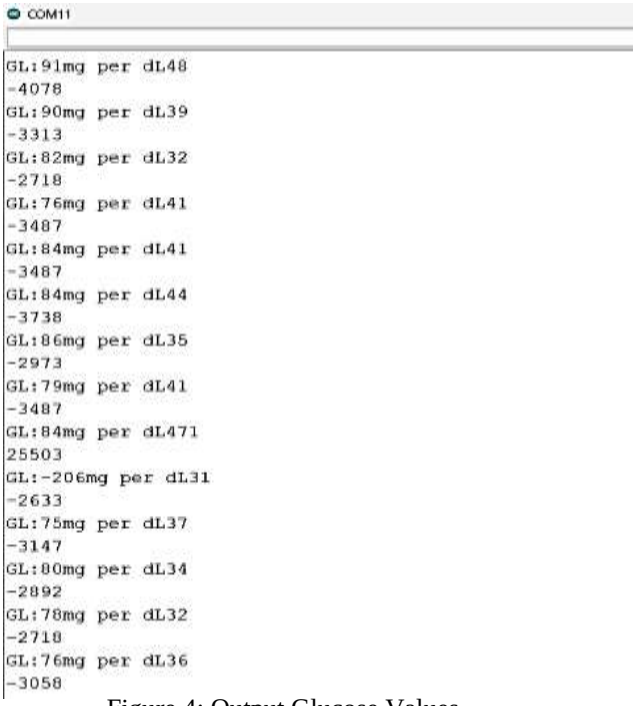

Figure 4: Output Glucose Values

Regression Analysis Using MATLAB

Data analysis is done with the help of MATLAB. Based on the recorded voltage values and corresponding glucose concentration a 1st order polynomial regression equation is computed which is used to calculate glucose concentration. The polynomial equation relating the analog voltage and the glucose level is computed by using a regression tool and shown below.

y = 0.3027x – 2.0673

where x and y are Analog Voltage (mV) and Glucose level (mg/dl) respectively.

Sl. No	Analog Voltage(mV)	Glucose Level(mg/dl)
1	499	142
2	509	146
3	519	156
4	519	157
5	548	169
6	524	159
7	543	157
8	568	150
9	573	179
10	583	183
11	592	195
12	597	187
13	607	185
14	627	175
15	695	180
16	735	220
17	612	200
18	847	247
19	883	248
20	867	276

Table 1: Analog Voltage and Glucose Level of Sample

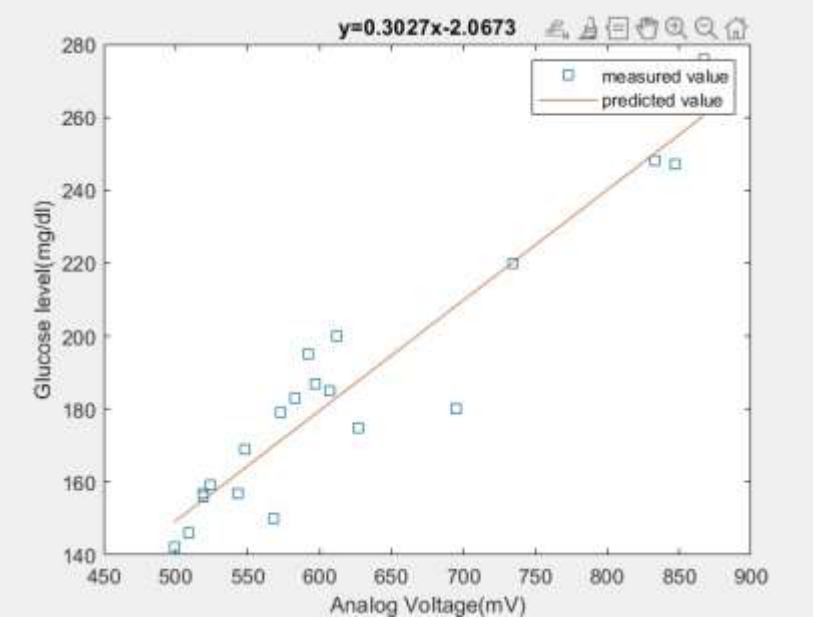

Figure 5 : Regression Equation Graph

Calculation of Accuracy

Sl No	Invasive	Non-invasive	Difference
1	116	103	13
2	105	102	3
3	98	98	0
4	129	120	9
5	126	122	4
6	132	130	2
7	106	100	6
8	103	111	8
9	108	108	0
10	112	105	7
11	128	119	9
12	122	124	2
13	124	121	3
14	91	81	10
15	120	115	5
16	124	131	7

Table 2: Accuracy Analysis

Figure 6: Non-Invasive Glucometer

Figure 7: Output Values

CHAPTER - 5

CONCLUSION

The development of non-invasive glucometers represents a significant advancement in diabetes management, offering a more comfortable and convenient alternative to traditional blood sugar testing methods. Through the utilization of technologies like NIR spectroscopy and wearable sensors, these devices provide real-time glucose monitoring without the need for invasive procedures. Our study has highlighted the potential of NIR-based glucose measurement systems, demonstrating promising results in terms of accuracy and reliability. However, challenges such as noise interference and skin conditions still need to be addressed to further enhance the performance of these devices. However, ongoing research and innovation could potentially transform diabetes care through non-invasive glucometers, leading to enhanced patient adherence and overall health improvements.

CHAPTER - 6

FUTURE SCOPE AND IMPLICATIONS

1. **Special filter and amplifier for noise reduction**: Design a filter and amplifier system that reduces interference or disturbances in the readings taken by the non-invasive glucometer. This ensures that the glucose level readings obtained are accurate and reliable, without being affected by external factors.
2. **Collect more blood samples for better results**: Increase the number of individuals from whom blood samples are collected to calibrate and validate the readings of the non-invasive glucometer. This extensive sampling helps in refining the accuracy of the device across a diverse range of individuals and conditions.
3. **Choose highly effective NIR sensors for precision**: Select Near-Infrared (NIR) sensors with superior sensitivity and accuracy to detect glucose levels in the blood more precisely, enhancing the overall performance of the non-invasive glucometer.

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APPENDIX

LIST OF COMPONENTS USED FOR THE PROJECT

SL.NO.	COMPONENT	VALUE	DETAILS
1	**ARDUINO UNO/ ESP8266**	1	1. **Arduino Uno**: Versatile microcontroller board based on an ATmega328P chip, ideal for prototyping and DIY projects. 2. **ESP8266**: Low-cost Wi-Fi module for wireless connectivity, commonly integrated with microcontrollers like Arduino Uno.
2	**LM358**	1	LM358 is a dual-operational amplifier with low cost and high gain, ideal for analog signal processing. It operates over a wide voltage range and temperature range, making it versatile for diverse electronic applications.
3	**RESISTORS** 6.8k 68 k 680 k 330 k 47 k	 3 2 2 1 1	Resistors are passive electronic components that limit the flow of electric current in a circuit. They are commonly used to control voltage levels, adjust signal levels, bias active elements, terminate transmission lines, and divide voltages.
4	**CAPACITORS**		Capacitors store and release electrical energy in the form of an electric field

	100 nF 1 uF	3 2	between two conductive plates separated by an insulating material. They are used in electronic circuits for filtering, decoupling, timing, coupling, energy storage, and noise suppression.
5	**MAX30102**	1	The MAX30102 is an integrated pulse oximeter and heart-rate sensor module, capable of measuring both SpO2 (blood oxygen saturation) and heart rate. It uses photoplethysmography (PPG) to detect changes in blood volume and oxygen levels, making it valuable for wearable health monitoring devices and medical applications.
6	**LCD Display**	1	Output Display

LIST OF SOFTWARE TOOLS USED FOR THE PROJECT

SL.NO.	SOFTWARE	VERSION/ DETAILS
1	**Arduino IDE** (Version 2.3.2)	The Arduino IDE (Integrated Development Environment) is a software platform for writing, compiling, and uploading code to Arduino and compatible microcontroller boards. It provides a simple yet powerful interface for programming Arduino-based projects, with features like code

		highlighting, serial monitor, and libraries for easy integration of sensors and peripherals.
2	**MATLAB** (R2024a)	MATLAB is a programming language and environment widely used for numerical computation and data analysis. It provides built-in functions and toolboxes for tasks like signal processing, image analysis, and control system design.